Cross-track Infrared Sounder (CrIS) CO_2 Information Content and Retrieval Sensitivity Study

Cong Zhou[1,2], Nadia Smith[1], Hung-Lung Allen Huang[1]

1. Cooperative Institute for Meteorological Satellite Studies, University of Wisconsin-Madison, Madison, Wisconsin
2. Joint Laboratory for Environmental Remote Sensing and Data Assimilation, East China Normal University, Shanghai, China

Introduction

Recently, at two sites in the Southern Great Plains and the North Slope of Alaska, a cause-effect relationship was established between carbon dioxide (CO_2) concentrations and top of atmosphere radiation that confirmed predictions of the atmospheric greenhouse effect due to anthropogenic emissions and the surface energy balance affected by rising CO_2 levels. Therefore, it is more important than ever to accurately measure and closely monitor atmospheric CO_2.

In 2011, the next-generation CrIS instrument was launched onboard the Suomi National Polar-orbiting Partnership (SNPP) platform and promises to extend the AIRS like CO_2 record. This work aims to characterize the information content (IC) of CrIS radiance measurements with respect to CO_2.

Materials

- **Data for background atmospheric state**
  - **Six standard climatologies: Tropical; Mid-latitude Summer; Mid-latitude Winter; Sub-arctic Summer; Sub-arctic Winter; US Standard**
  - **Community Satellite Processing Package (CSPP) NOAA Unique CrIS/ATMS Product System (NUCAPS) CrIS real-time direct broadcast products: Temperature (T), Water vapor mixing ratio (Q) and Ozone (O_3) profiles**
- **Radiative transfer model**

  Radiative Transfer for TOVS (RTTOV) v11.2
- **Instruments**

  Atmospheric Infrared Sounder (AIRS) on Aqua;

  Infrared Atmospheric Sounding Interferometer (IASI) on MetOp-A;

  CrIS on SNPP (See Table 1 for detailed information)

Table 1. Instrument characteristics for AIRS, IASI and CrIS

	AIRS	IASI	CrIS
Launch date	4 May, 2002 (Aqua)	19 Oct., 2006 (MetOp-A) 17 Sep., 2012 (MetOp-B)	28 Oct., 2011 (Suomi-NPP)
Overpass time (LT)	13:30 Descending mode	9:30/08:45 Descending mode	13:30 Descending mode
Altitude (km)	705.3	~817	824
Instrument type	Grating spectrometer	Fourier Transform Spectrometer	Fourier Transform Spectrometer
Spectral Range	649 to 2674 cm^{-1}	645 to 2760 cm^{-1}	650 to 2550 cm^{-1}
Spectral resolution	$\lambda/\Delta\lambda = 1200$ (0.5 to 2 cm^{-1})	0.35 to 0.5 cm^{-1}	SW: 2.5 cm^{-1} MW: 1.25 cm^{-1} LW: 0.625 cm^{-1}
Channel number	2378	8461	1305
Swath Width	1650 km	~2200 km (±48.3◦)	2200 km (±50◦)
IFOV (km)	13.5	12	14

- **Information Content**

  Degrees of Freedom for Signal (DFS): the number of independent pieces of information in a measurement that can be observed above the noise of the observations (Rodgers C D, 2000)

$$A = GK = (K^T S_\epsilon^{-1} K + S_a^{-1})^{-1} K^T S_\epsilon^{-1} K$$
$$d_s = tr(A)$$

K: Weighting function matrix [nchan × nchan]

S_ϵ: Measurement error covariance [nchan × nchan]

S_a: Background uncertainty covariance [nlev × nlev]

d_s: DFS

NOTE:

(1) Measurement error is the square of the noise equivalent delta temperature (NeDT) with zero off-diagonal values.

(2) S_a is set to T, Q, and CO_2 background uncertainty, respectively.

(3) All simulations here are noise free.

Sensitivity of CO_2 IC to Instrument Noise and Selected Channels

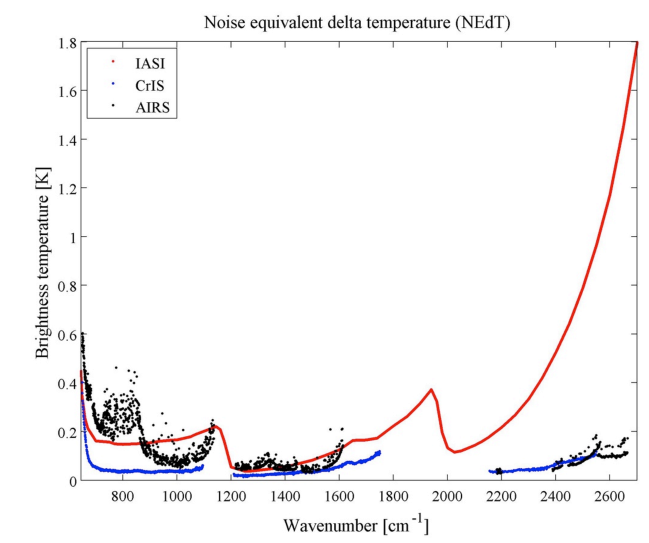


Fig 1. Instrument noise of AIRS, IASI, and CrIS (NeDT for a 280K brightness-temperature scene).

- **CrIS instrument has a significantly lower noise level than AIRS and IASI (Fig 1).**

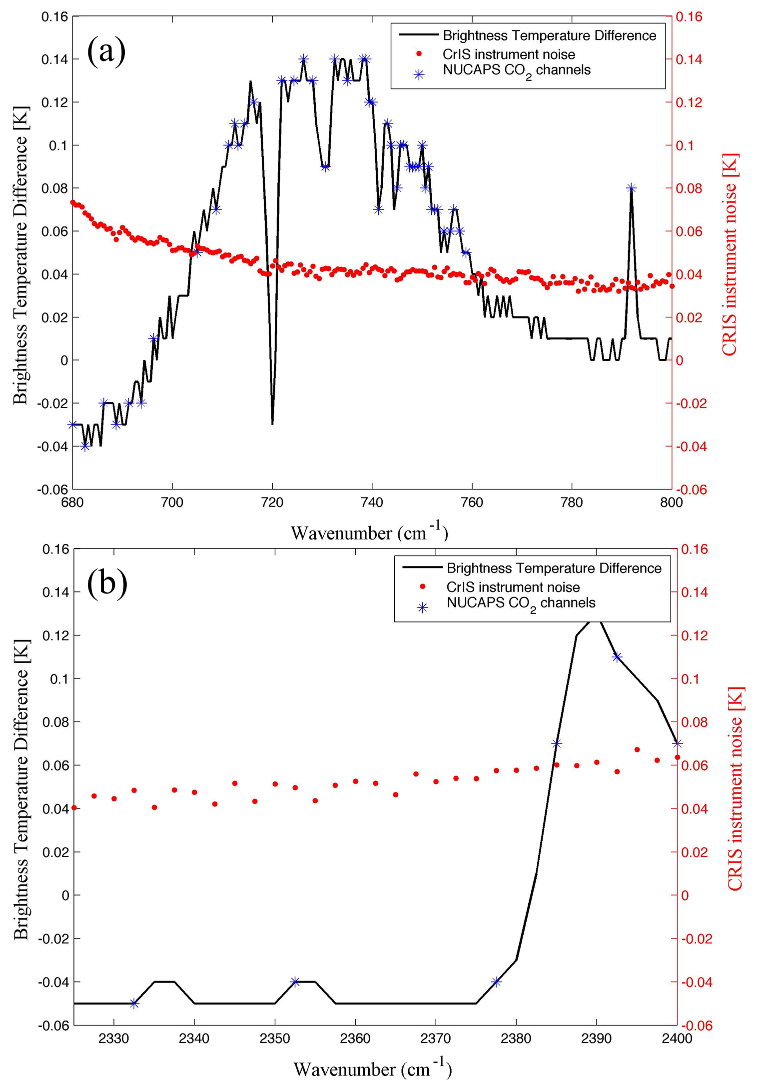
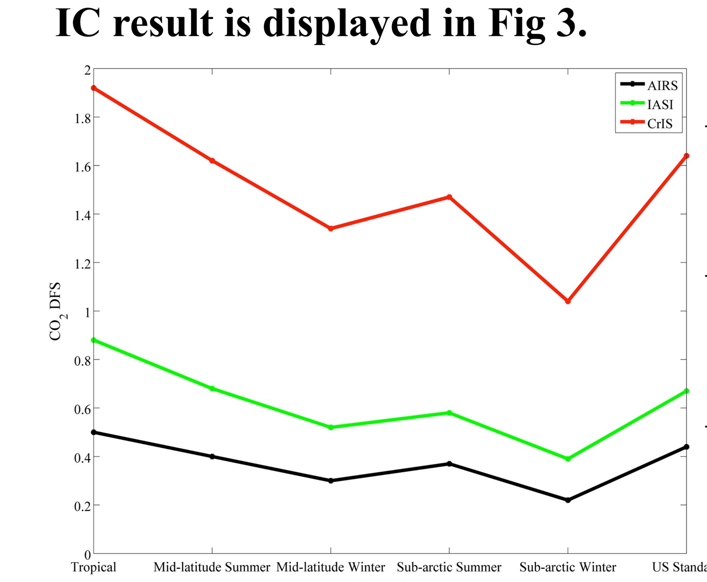


Fig 2. Brightness temperature difference and instrument noise zoomed in NUCAPS selected LW (a) and SW(b) CO_2 channels .

- **In Fig 2, we increased CO_2 data by 1% and calculated the brightness temperature difference based on US Standard profile for CrIS. Two figures were zoomed into NUCAPS selected CO_2 channels (blue star). For most selected channels, the instrument noise is lower than 1% (~3.7 ppmv) CO_2 sensitive value.**

- **Here, we set the background uncertainty for T= 1K, Q= 20% and CO_2= 2ppmv. The IC result is displayed in Fig 3.**



- **The information content values for CO_2 of CrIS are almost four times higher than AIRS and three times higher than IASI.**
- **We found that skin temperature doesn't have an clear impact on information content to T, Q, or CO_2 (not shown here).**
- **CO_2 IC result shows an clear seasonal variation.**

Fig 3. IC result with respect to CO_2 based on 6 climatologies.

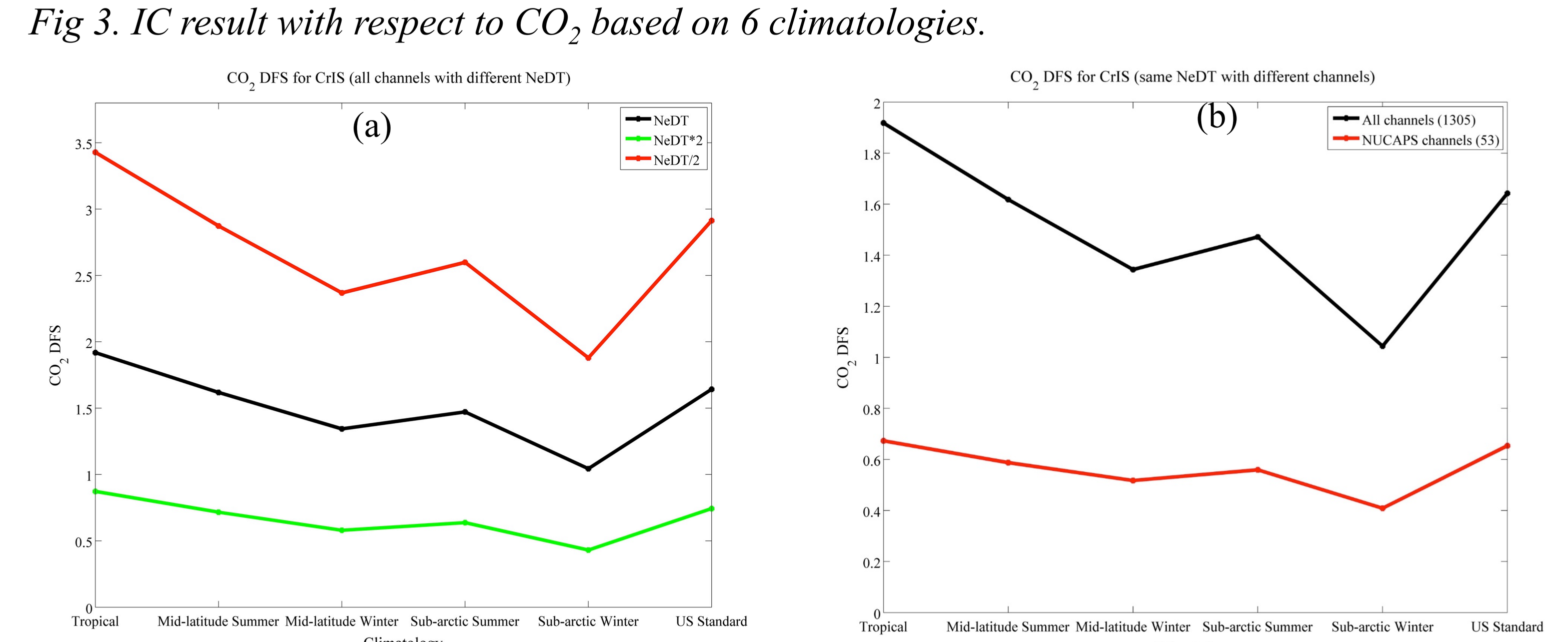
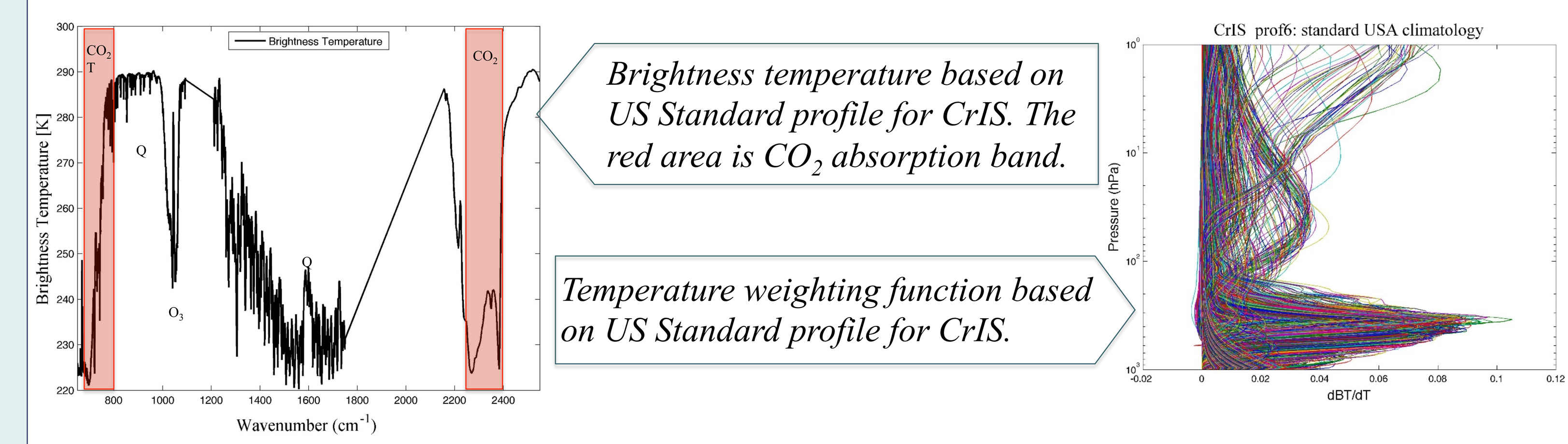


Fig 4. CO_2 DFS variation for CrIS based on all channels with different NeDT (a) and same NeDT with different channels (b).

- **Instrument noise has a great impact on CO_2 DFS. Almost twice information is contained with halved noise (Fig 4 (a)). The lower the noise is, the higher DFS and more clear seasonality are presented.**
- **The values of CO_2 DFS for all channels are between 1 to 2 with distinct seasonality, while CO_2 DFS for NUCPAS selected channels has stable values all below 1 showing weak seasonal variation.**

Sensitivity of CO_2 IC to Background Values of T, Q, O_3

- **Case 1: CSPP NUCAPS T profile & US standard climatology for all other parameters**
- **Case 2: CSPP NUCAPS Q profile & US standard climatology**
- **Case 3: CSPP NUCAPS O_3 profile & US standard climatology**



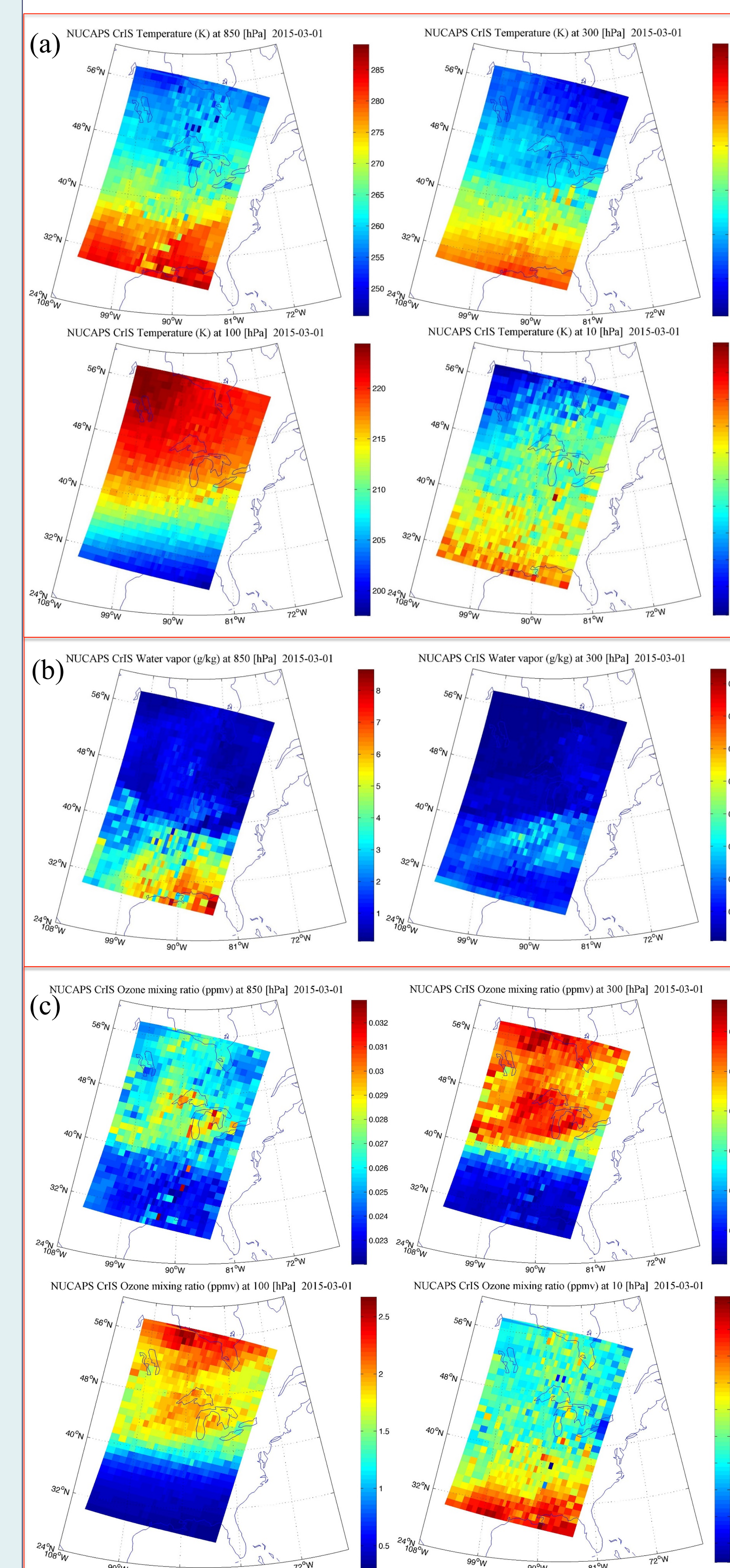


Fig 5. Spatial distribution of CSPP NUCAPS CrIS T (a), Q (b) and O_3 (c) on different pressure levels.

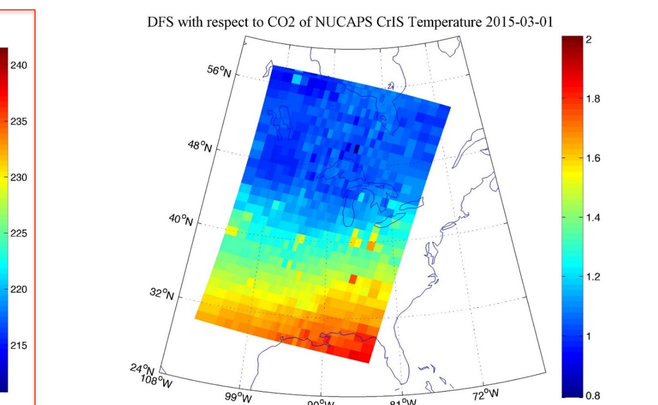


Fig 6. Spatial distribution of CO_2 DFS for Case 1 using all channels.

- **CO_2 DFS is temperature dependent, affected by local T variation. The spatial distribution is consistent with 300 hPa T distribution, which is according to weighting function peak.**

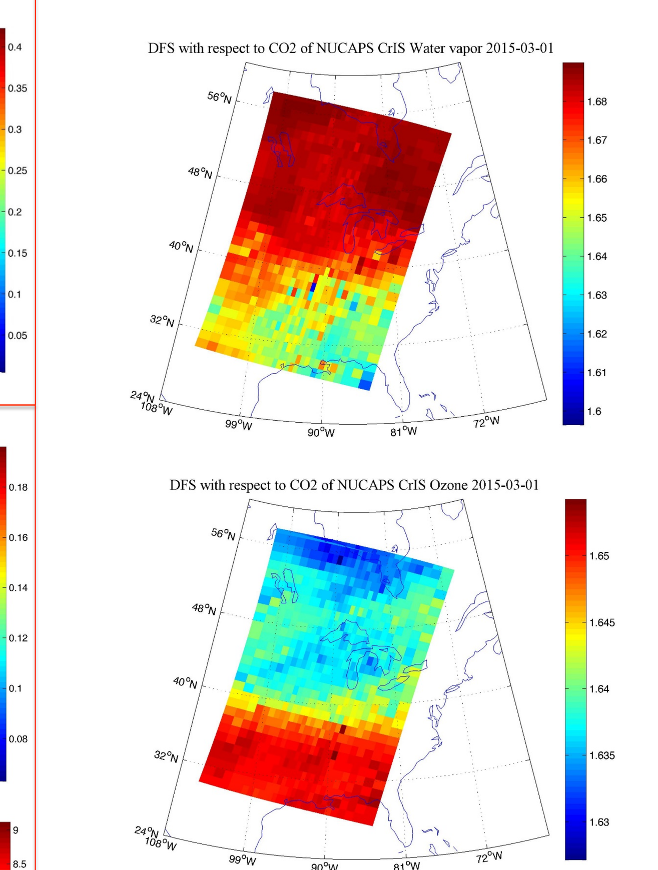


Fig 7. Spatial distribution of CO_2 DFS for Case 2 (top) and Case 3(bottom) using all channels.

- **The impacts of Q and O_3 on CO_2 DFS are negligible with slightly variation, which maybe affected by noise.**

Future work

- **Use ECMWF and GDAS products to investigate the impact of uncertainty in atmospheric background on CO_2 information content.**
- **Analyze the impact of atmospheric background from different scales.**

Contact: Cong Zhou, cong.zhou@ssec.wisc.edu